Advanced Deep Space Power Systems

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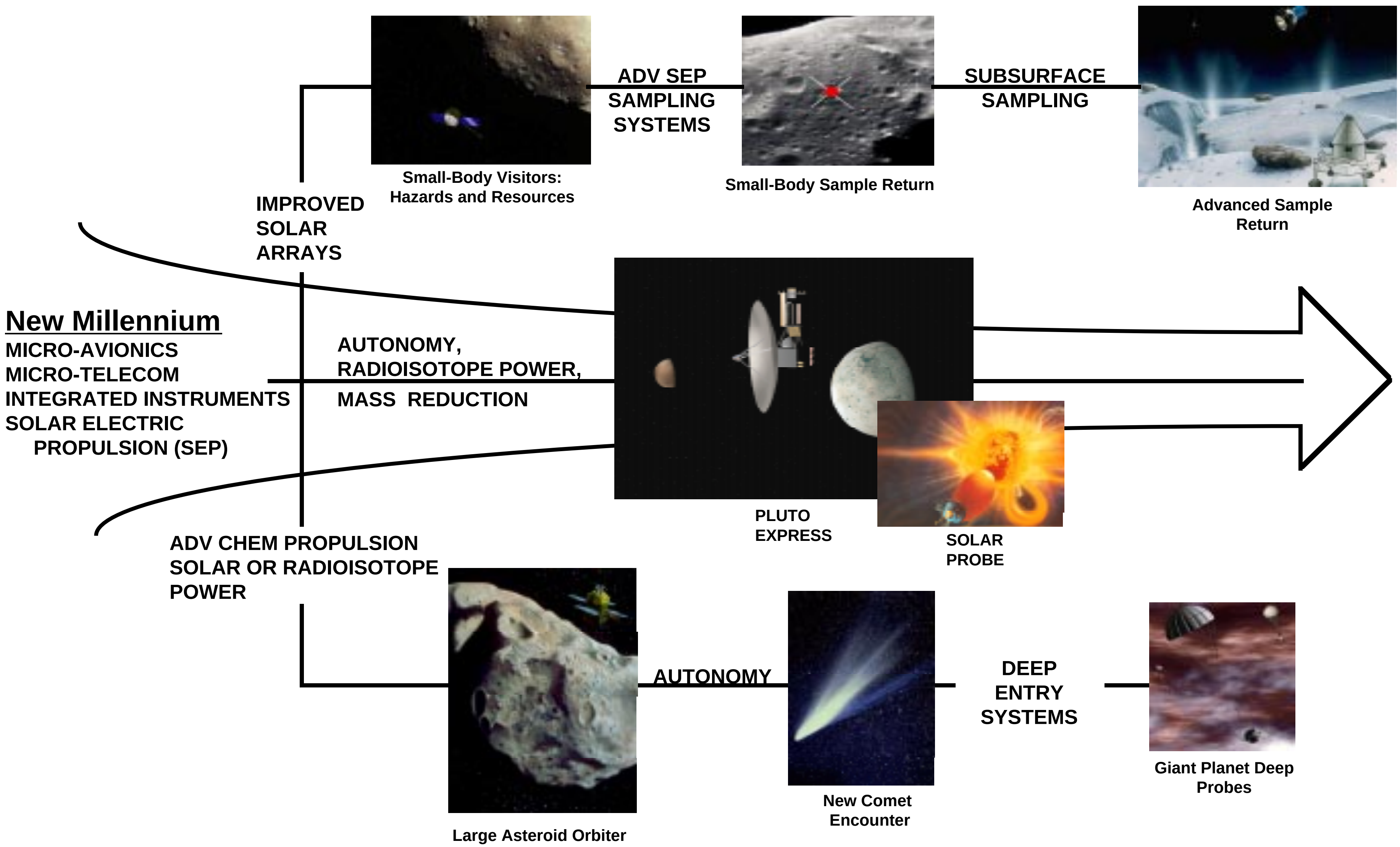
Building Blocks and Our Chemical Origins

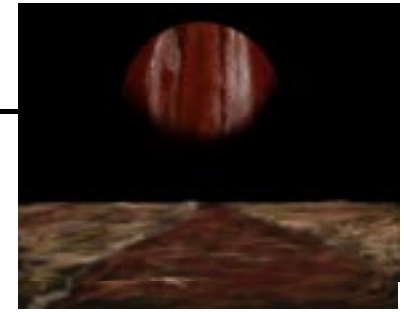
Example Campaign Roadmap



Pre-Biotic Chemistry in the Outer Solar System

Example Campaign Roadmap

AIRLESS-BODY LANDER
MINIATURE GEOPHYSICS LAB

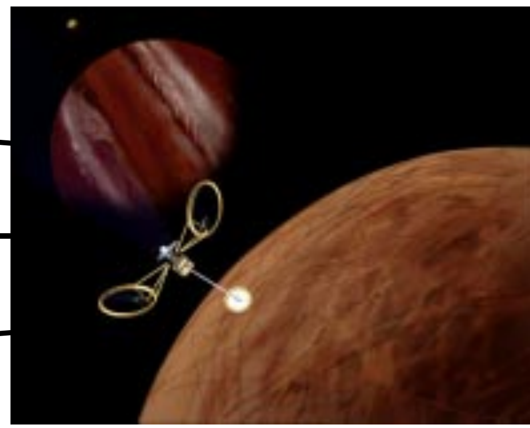


Europa Internal Structure

New Millenium/
Pluto Express

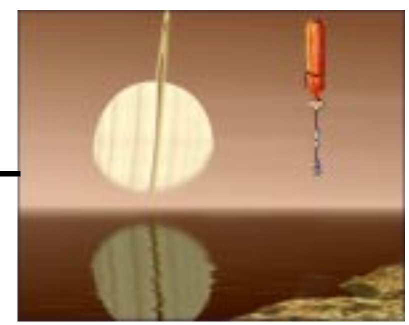
MICRO-AVIONICS
AUTONOMY
RADIOISOTOPE
POWER

RADIATION TOLERANCE
ADV CHEM PROPULSION
ADVANCED SOLAR
POWER (OPTION)



Europa Ocean Explorer

AEROBOT TECHNOLOGIES
AEROCAPTURE
MINIATURE CHEMISTRY LAB



Titan Biologic Explorer

Deep Space Science Mission Imperatives

- Small, low cost spacecraft
- Low power, excepting electric propulsion missions
- Severe environments
  - Low temperatures: 100K to 700K
  - Radiation
  - Atmospheres
  - High-G impacts
- New technology enabling

Spacecraft Systems Power Technology Program

- Photovoltaic Conversion Technology
- Space Environmental Effects
- Advanced Battery Development
- Fuel Cell Systems Development
- Aerospace Flywheels
- Power Management and Distribution
- Electro-Physics Technology Development
- Low Temperature Electronics
- Electro-Mech & Thermo-Mech Systems Development
- Centers for Space Power

Spacecraft Systems Power Technology Program

Requirements

	Space Science	MTPE	HEDS	Commercial Comm.	DOD	Aero
Batteries	>300 Whrs/kg for high ? rate of discharge ≥175-250 W-hr/liter, >100-140 W-hr/kg secondary batteries capable of > several thousand cycles >600 W hrs/kg for low ? rate of discharge Low temperature batteries < -120C 3 x increase in Battery W-hr/kg	Low weight, high energy storage, high DOD batteries 60 W-hr/kg 30,000 cycles	Low weight, high energy density high DOD batteries w/long cycle life >30,000 cycles (ISSA)	Batteries with reduced energy storage mass 1/3 in 5 years 1/10 in 10 years Advanced NiH_2 Li ion Li solid polymer Reduced volume long cycle life	Adv. energy storage high w-hr/kg long cycle life high DOD reduced volume Li Ion/SP NaS	High energy density storage ERAST
Fuel Cells			Lunar base PV/RFC Shuttle upgrade Vehicles (also transportation)	PV/RFC Terrestrial FC power plants	PV/RFC Remote base power ship, terrestrial power	High energy density storage ERAST
Flywheels		Alternate high energy efficiency storage >90% efficient 1 - 2 kW ES + AC	High energy density storage ISSA Shuttle upgrade EMA drive	High energy density storage 10 x SOA ES + AC	High energy density storage 10 x SOA ES + AC	ES for EMA drives peak power
Other	Molten salt storage					

? May not be currently addressed in program

Spacecraft Systems Power Technology Program

Requirements

	Space Science	MTPE	HEDS	Commercial Comm.	DOD	Aero
Photovoltaics (advanced solar power)	Advanced low intensity temperature (LILT) high efficiency array, 100 - 200 W/kg 25% efficiency; volume efficiency >200 W/m² Increased Deployable Surface Power with low mass, solar arrays >20% efficiency operational at <-40 deg C * RAD hard arrays >1 MRAD 2x increase in array efficiency Low cost, reliable safe power systems 1/3 cost	High efficiency solar array >20% 50 W/kg	High efficiency solar array (LMI, ISSA)	Increased power/ mass power generation MBG cell, concentrators Thin film - low cost cells AmSi, CIS Solar cell availability	High efficiency MBG cells ≥ 30% Low cost survivable concentrator arrays Advanced lightweight thin-film arrays	High efficiency light weight cells - ERAST

* Not currently being addressed in program

Advanced Radioisotope Power Sources

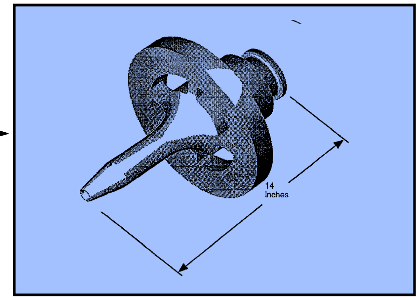
Advanced Technologies:

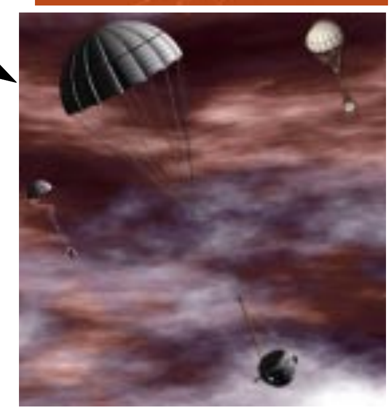
Ö **New heat source**
- 2 to 4 W_t class
- 60 to 120 W_t class

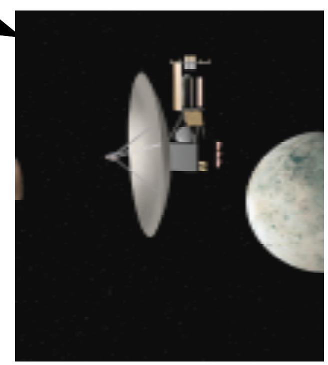
Ö **New converters**
- 0.10 W_e class
- 10 W_e class
- 100 W_e class

Ö **New thermal mngt.**
- Microspacecraft RHU

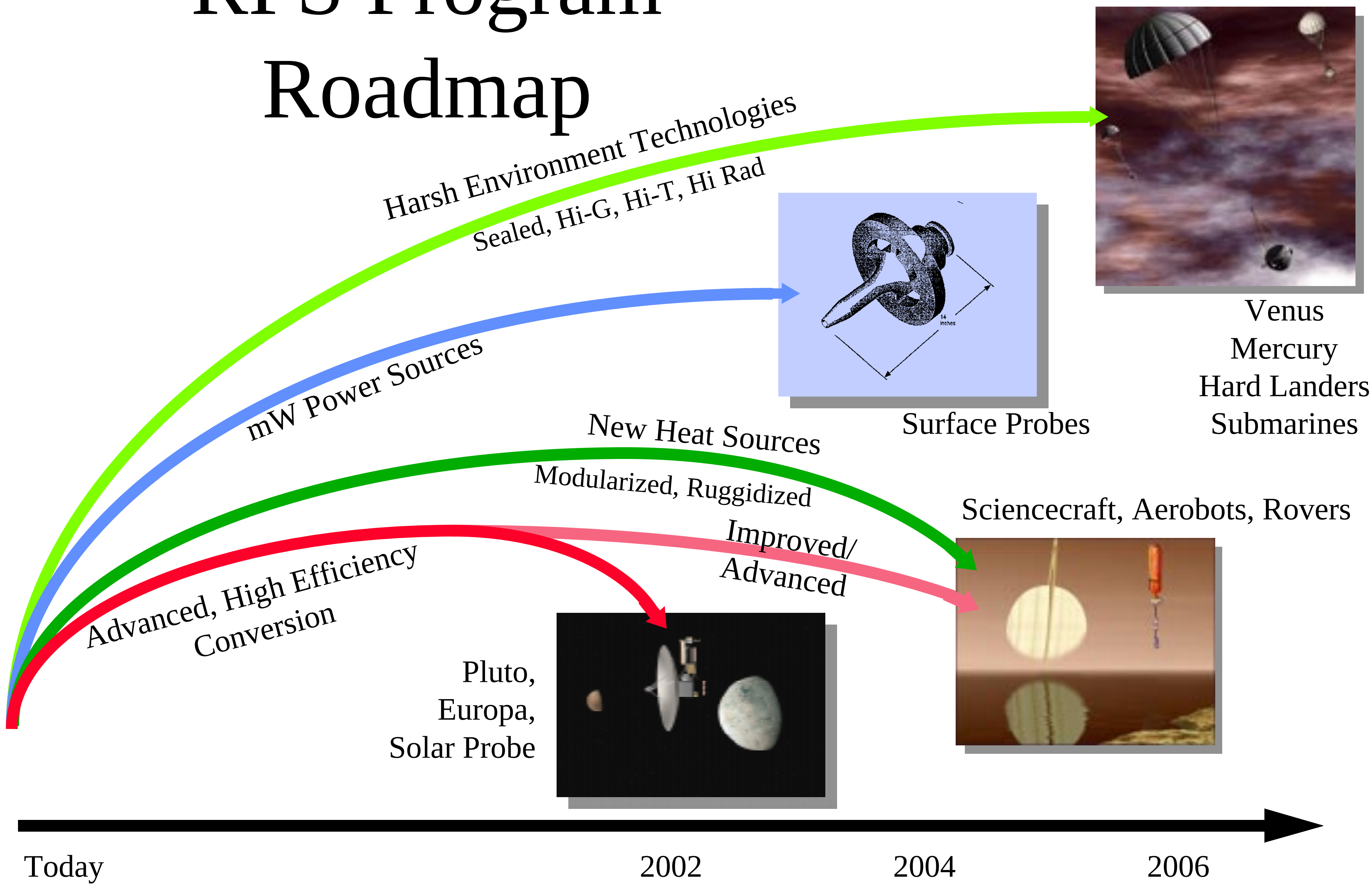
Ö **Harsh environments**
- Hermetically sealed
- High “g”
- High temperature
- High pressure
- High radiation dose





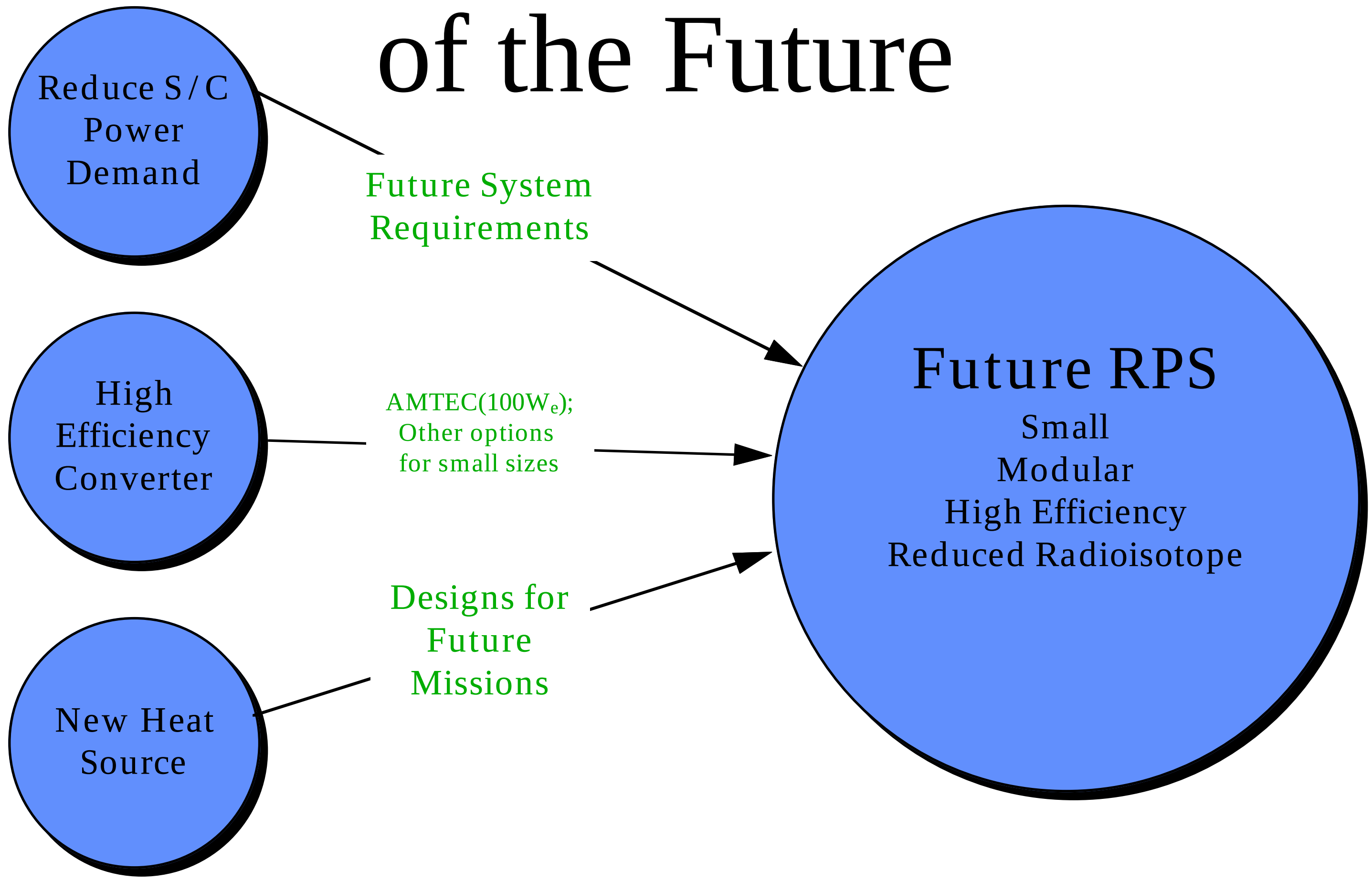


RPS Program Roadmap



The Radioisotope Power Source of the Future

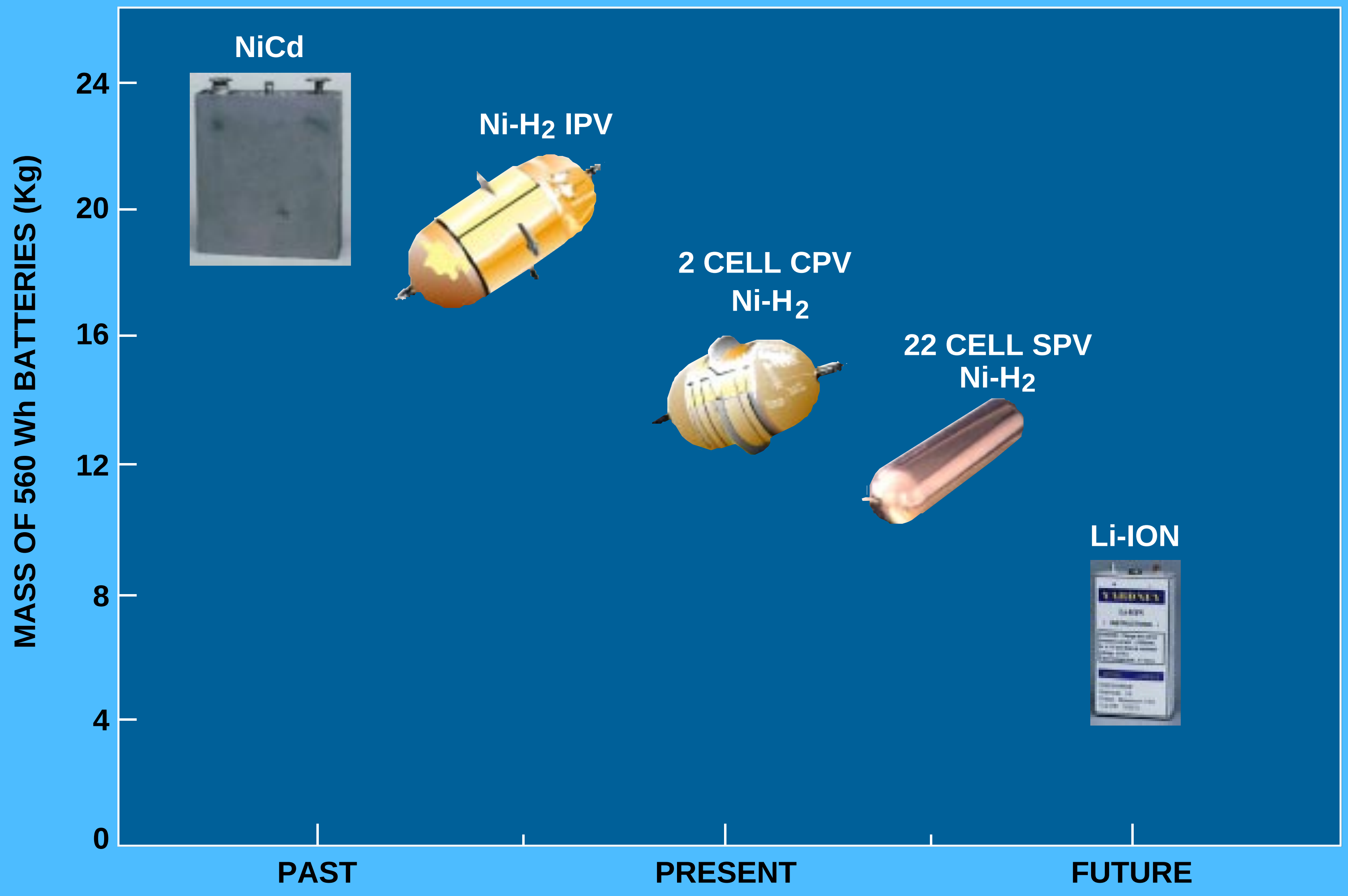
Technology Developments



Battery Status and Needs

- Nickel-hydrogen designs now in common use by deep space science mission planners
- Lithium-ion is the future technology of choice and development is accelerating dramatically.
  - 5000+ cycles on small cells
  - Scale-up to 20 Ah
- Extreme environments:
  - Primary Lithium to -80° C; Li-ion to -20° C or lower
  - High temperature?
- More emphasis on integrated concepts needed.

ADVANCED LITHIUM SPACECRAFT BATTERIES



Spacecraft Systems Power Technology Program

FY96 Accomplishments

Technology Development of Dual Use Rechargeable Lithium-Ion Polymer Batteries

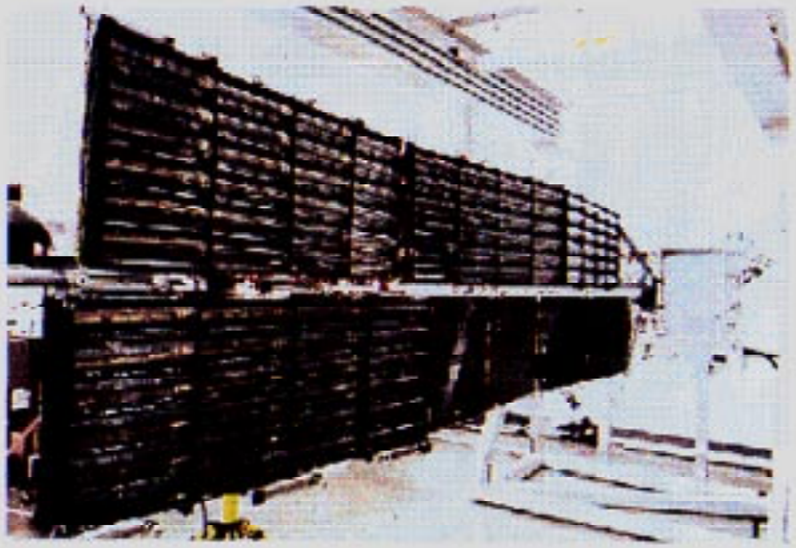
- **Cooperative TRP effort very successful**
  - Progress made toward replacement of NiCd batteries for Military and space users
- **Major performance and manufacturing advances achieved for dual-use applications**
  - Demonstrated 3x specific energy of SOA NiCd toward target of 200 Whr/kg (6x NiCd)
  - Automated production capability and development
- **Penetration of markets for laptop computers, portable military applications and NASA missions is imminent**
- **Combination of in-house, industry, university (CSP) and SBIR efforts being pursued to extend life, increase energy density and power density of lithium-ion solid polymer battery**

Battery cells and cell packs currently being tested by commercial, military and NASA end users

PV Status and Needs

- 19% efficiency is flying; 20+% efficiencies about ready to fly; 30% is in sight
- Concentrators also about to fly
- First low mass structures developed; development of inflatables accelerating
- Work on radiation hardness proceeding
- New integrated system concepts under study

Advanced Photovoltaic Concentrator Arrays



SCARLET I / METEOR FLIGHT HARDWARE

Applications For Future Space Missions:

- High Radiation Environments
- Deep Space Planetary Missions
- Direct-Drive Electric Propulsion Systems
- Commercial Systems
- Low Cost (< 1/2 Current Planar Arrays)
  - Reduced cell costs (1/20 Typical)
  - Manufacturing & Assembly costs reduced 50%
- High Performance
  - Smaller array area, low weight (>300W/m^2,80 W/kg
  - Increased off-pointing tolerance

Technology Provider: Lewis Research Center

Technology Development Area: Spacecraft Systems - Team 1

Technology Customers: Transportation and Space Station, Commercial Communication, MTPE, Space Science, HEDS,DoD

Objectives:
- Reduce Solar Array Cost
- Improve Radiation Tolerance
- Minimize Interactions with Space Environment

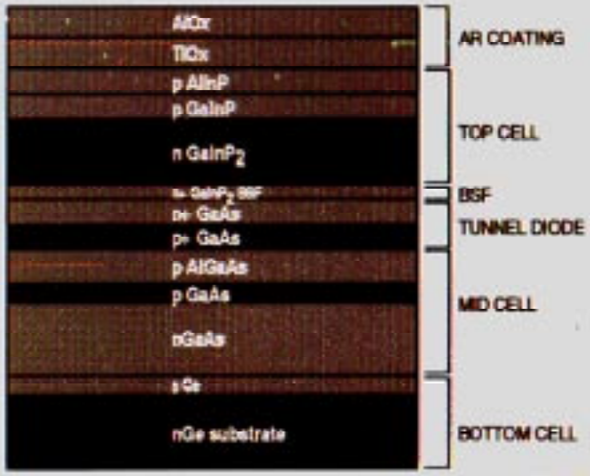
Approach:
- Scarlet - Joint BMDO/NASA Program on Linear Refractive Concentrators

Deliverables and Schedules:
- Deliver 2.6 kW Flight Array for NASA New Millennium DS-1 Mission **4Q 97**
- STRV 1C/D Flight Experiment **4Q 98**

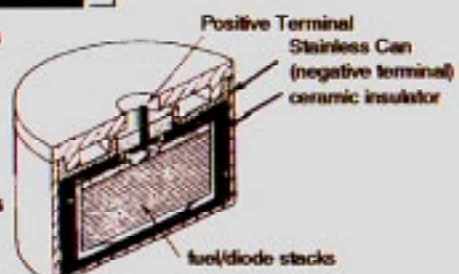
Budget ($K):

Code SM	FY97	FY98	FY99	FY00
	485	315	160	160

Advanced Photovoltaic Cell Development



3 Junction MBG Cells



Alpha Voltaic Devices

Applications For Future Space Missions:

- $\geq$ 1.3x reduction in array area over Advanced SOA (2 Junction MBG Cell, eg)
- Enable long-life, distributed power sys. architecture for low power applications (Few Watts $\longrightarrow$ 10's Watts)

Applications For Ground:

- Multiple dual use applications for α & β voltaic devices

Technology Provider: **Lewis Research Center**

Technology Development Area: Spacecraft Systems - Team 1

Technology Customers: Commercial Communications, DoD, Aeronautics, Space Science, MTPE, HEDS

Objectives:

- High Efficiency Solar Cells based on New Materials and Designs; non-solar, solid state energy conversion technology for distributed power system architecture

Approach:

- 3 Junction MBG Cells; Alpha & Beta-Voltaic Devices

Deliverables and Schedules:

- 3 Junction MBG Cells $\geq$ 30% efficiency demo **1Q 99**
- $\geq$ 15% efficient α & β device demo **4Q 99**

Budget ($K):

	FY97	FY98	FY99	FY00
Code SM	120	235	395	395

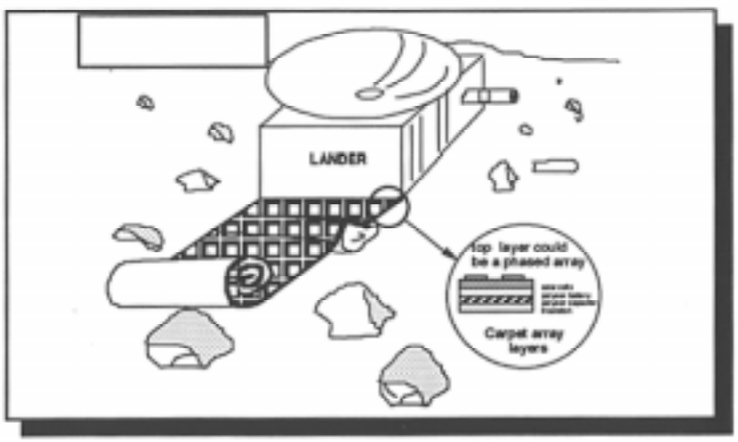
Examples of Integrated “Systems”

- Combined PV and RF systems
- Combined PV cell and chemical energy storage
- Combined radioisotope power source chemical energy storage
- Chemical energy storage at the sensor head or “chip” level
- Attitude control and flywheel energy storage

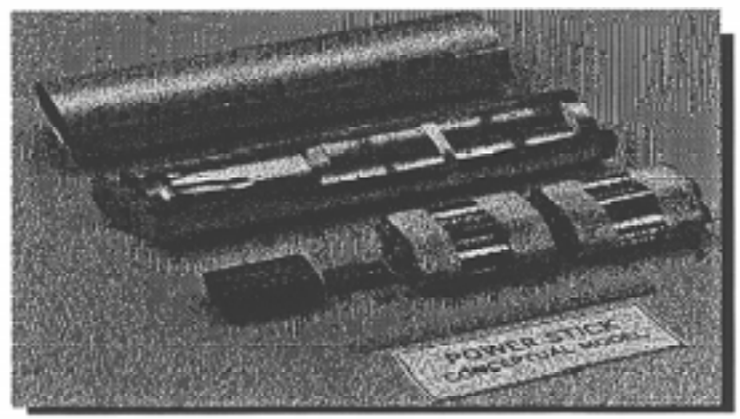
Power for Small Vehicles and Spacecraft

LEADING TECHNOLOGIES

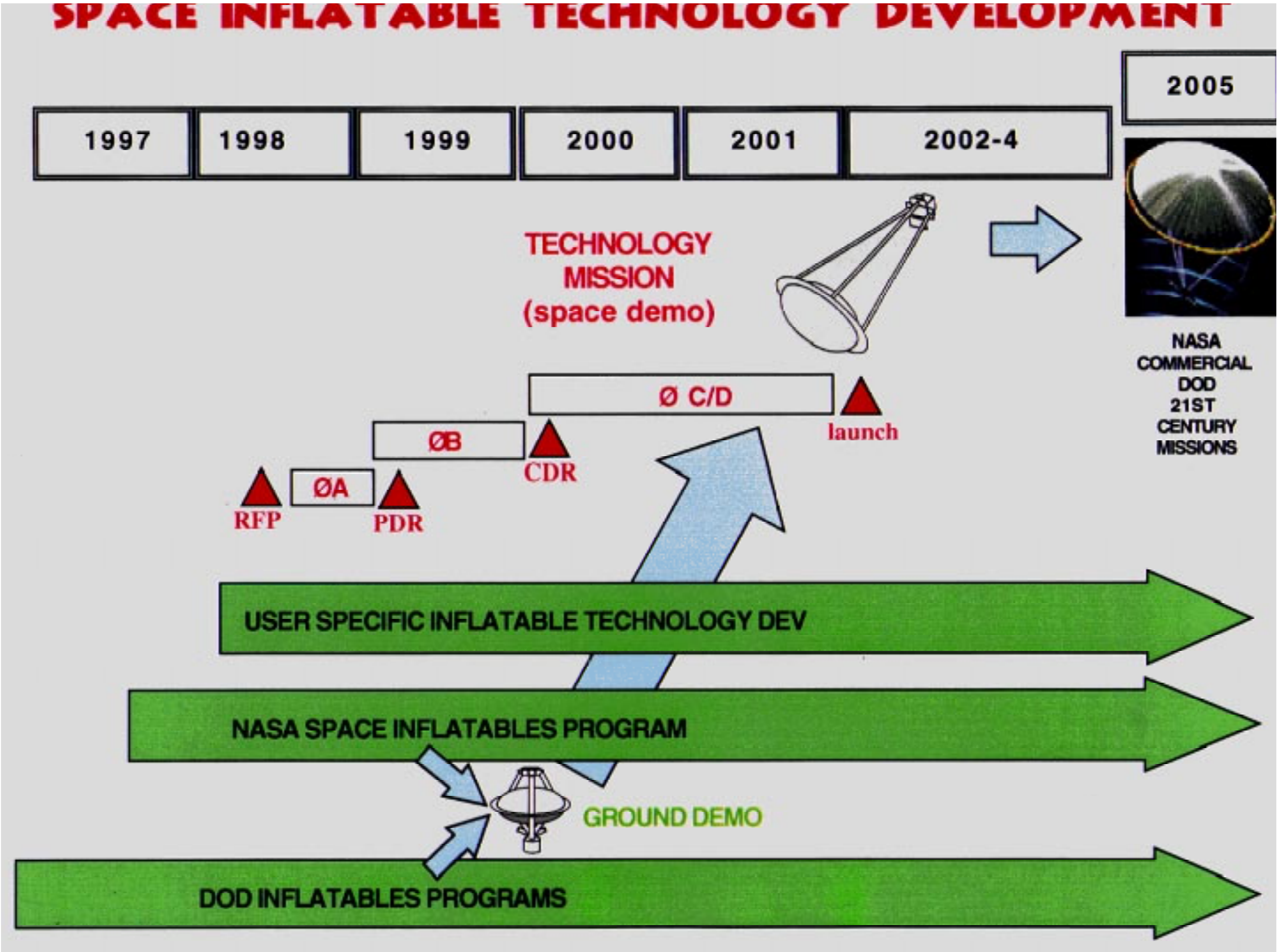
- Small photovoltaic blankets for surface rovers and landers
- Shock-resistant small arrays for penetrators
- Extreme temperature batteries
  - Primary/secondary batteries operational at –100°C
- Very small long-life power source for planetary surfaces and non-sunlit areas
  - Small radioisotope units coupled to converters/batteries
  - "Trickle charge" of 1–10 milliwatts
  - Power storage and "burst mode" operations



Station with Photovoltaic Blanket

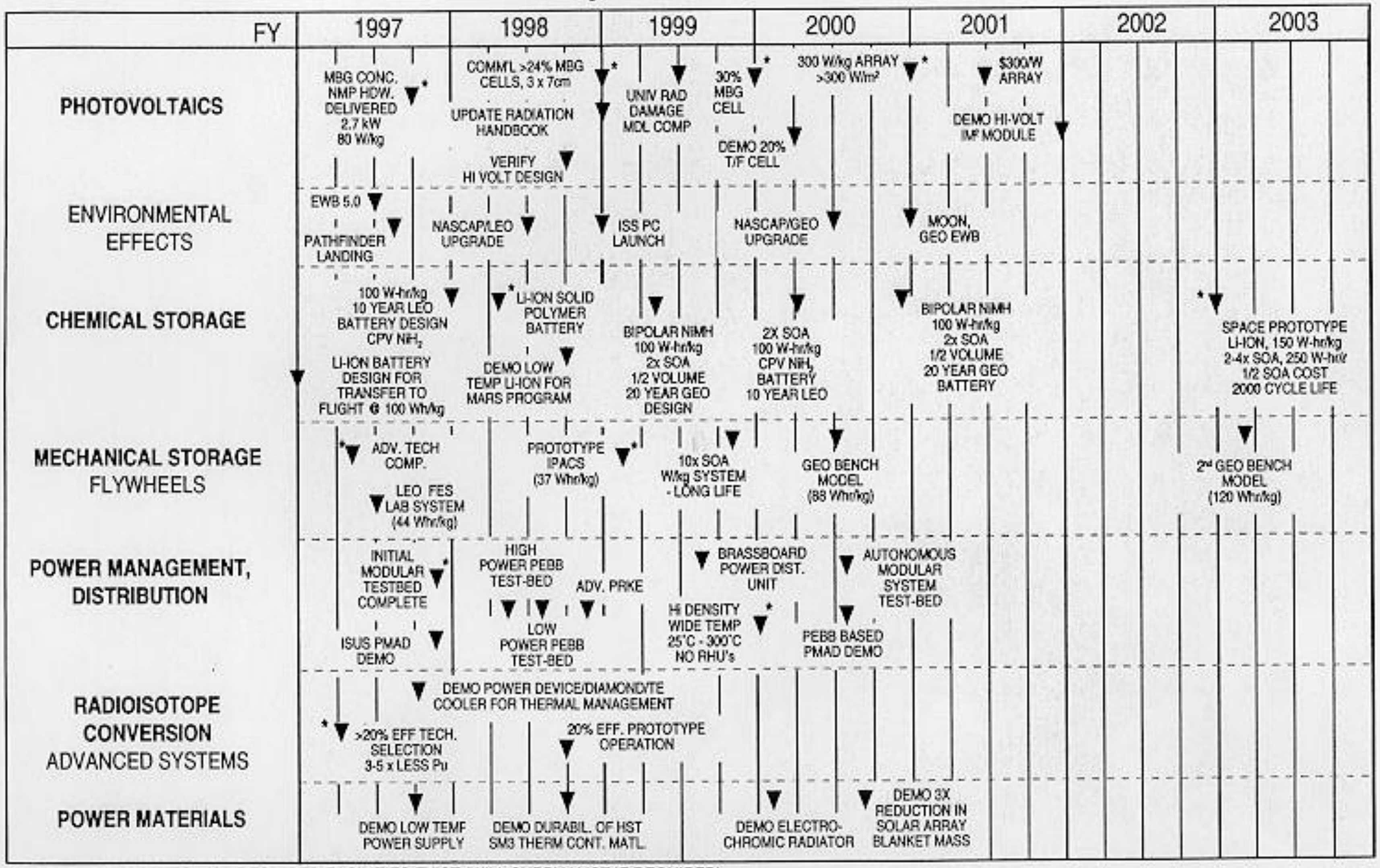


Power Stick


SPACE INFLATABLE TECHNOLOGY DEVELOPMENT
1997
1998
1999
2000
2001
2002-4
2005
TECHNOLOGY
MISSION
(space demo)
Ø C/D
launch
ØB
CDR
ØA
RFP
PDR
NASA
COMMERCIAL
DOD
21ST
CENTURY
MISSIONS
USER SPECIFIC INFLATABLE TECHNOLOGY DEV
NASA SPACE INFLATABLES PROGRAM
GROUND DEMO
DOD INFLATABLES PROGRAMS

Spacecraft System Power Technology Program

Major Milestones



UNIQUE FACILITIES - ALL REQUIRED FACILITIES EXIST (WILL SUPPLY LIST IF REQUIRED)

RJS-OMB97-002.2 rev.

* INDICATES JOINT, CO-OPERATIVE PROGRAM, FUNDING LEVERAGE

Workshop Objectives

- Identify Advanced Concepts
- Identify applications and ***BENEFITS***
- Assess maturity
- Identify key issues and milestones
- Innovation is expected

Power Splinter Groups

- Solar:
  - Multifunctional Systems
  - Advanced Concepts
  - Planetary In Situ Power Systems

- Radioisotope:
  - Multifunctional Systems
  - Advanced Converters (for small power sources)
  - Advanced Heat Source Concepts

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